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THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1897

THE LAST GREAT BALTIC GLACIER.

IN a recent number of this JOURNAL[1] Dr. Keilhack criticises certain views which I have been led to entertain as to the glacial succession in northern Europe. He does not agree with me that the great terminal moraines of the Baltic Ridge are the products of a separate and independent glacial epoch. On the contrary, he and his colleagues on the Royal Prussian Geological Survey are persuaded that the moraines in question simply mark a stage in the retreat of the third ice-sheet. In the last edition of the *Great Ice Age* I have stated somewhat fully the evidence for the conclusion which my critic now disputes, and a short outline of the subject subsequently appeared in this JOURNAL[2].

Geologists who may wish to know what my views are will, I hope, take my own account of them rather than that which Dr. Keilhack has presented to his readers. Doubtless the discussion has been conducted by him in good faith and with every intention of being just, but, all the same, he has not succeeded in giving an accurate outline of the reasons which compelled me to dissent from the opinions maintained by him and his eminent colleagues. Some of the more important evidence adduced he either ignores or slurs over, while in certain other matters he has strangely misunderstood and thus unwittingly misrepresents me. Having carefully considered Dr. Keilhack's paper, I find that his criti-

[1] Vol. V, No. 2, pp. 113-125.

[2] Vol. III, p. 241.

cisms go wide of the mark; he has failed to meet my argument, and I have nothing to modify or withdraw. Under these circumstances I might well leave what I have already written on the subject, and simply appeal to it as a sufficient reply to Dr. Keilhack. Silence on my part, however, might be misunderstood, and I would not appear to be discourteous to a geologist whom I highly esteem, and whose work no one can value more than myself. At the risk of being tedious, therefore, I shall again shortly state my reasons for the faith that is in me, and take due note of my critic's objections.

It was while studying certain glacial phenomena in Britain that I was first led to inquire more fully into the grounds upon which German geologists base their belief that the terminal moraines of the Baltic Ridge were deposited during the retreat of the third ice-sheet (Polandian). The evidence which impressed me in Britain may be very shortly outlined. We have two well-recognized bowlder clays developed in the low grounds of our country— the lower of which belongs to the epoch of maximum glaciation (Saxonian), at which time the British and Scandinavian ice-sheets were coalescent. The upper bowlder clay is the ground-moraine of a less extensive, but still immense, ice-sheet, which, like its predecessor, also occupied the basin of the North Sea, so that continuous inland ice extended as before between Norway and Britain. During the formation of the lower bowlder clay the Scandinavian ice invaded East Anglia and the midlands of England, but this invasion was not repeated by the succeeding ice-sheet. Nevertheless, we have no doubt that the British and Scandinavian ice-sheets were again confluent. Along the whole eastern seaboard of Britain, from Flamborough Head to the extreme north of the Scottish mainland— a region over which the upper bowlder clay is strongly developed— all the evidence indicates that the British ice, underneath which that clay accumulated, was steadily deflected to right and left as it passed outwards into the North Sea basin. North of the Firth of Forth the trend of all the stones in the upper bowlder clay, as well as the direction of drumlins, of roches moutonnées and striæ are towards northeast, north, and, eventually, northwest. South of the Firth, on the other hand, the direction of glaciation is southerly. In a word, it is demonstrable that *during the formation of the upper bowlder clay the British ice did not follow its natural course and flow directly outwards into the basin of the North Sea. It was deflected just in the same way as the earlier inland ice of the Saxonian stage had been.* So far, indeed, as Scotland was concerned, the ice-sheet of Polandian times was hardly less important than its predecessor.

The upper bowlder clay is the chief glacial accumulation in our lowlands, and its surface is often concealed under more or less continuous sheets of gravel and sand, while here and there it is dotted over with large erratics and traversed by eskers. All these obviously belong to the period of melting. Nowhere, however, is a vestige of terminal moraine encountered until the base of the uplands and mountains is approached. Here well-developed terminal moraines suddenly put in an appearance—the relics of large valley-glaciers and local or district ice-sheets. For a long time the general belief was that these moraines had been accumulated during the retreat of the last general ice-sheet (Polandian). Further investigation, however, proved that the outermost moraines had been laid down by advancing glaciers, which had everywhere ploughed into the upper bowlder clay, sweeping it out of the valleys, and so modifying its surface in the low grounds at the base of the mountains as to impress upon it a new configuration. The dimensions of the moraines, the extent of their fluvio-glacial gravels, and the amount of erosion experienced not only by the upper bowlder clay, but by the solid rocks themselves, all indicate that these valley-glaciers and local ice-sheets mark a distinct stage of the Glacial Period.

Again, there is evidence to show that after the retreat of the ice-sheet of the upper bowlder clay, and before the valley-glaciers in the west of Scotland had descended to the coast, the maritime districts were slightly submerged. Loch Lomond at that time formed an arm of the sea, and was tenanted by a fauna which consisted for the most part of existing British forms.

Subsequently a large valley-glacier entered the fiord, filling it up, and ploughing out preëxisting marine deposits. By this time, however, the climate had become arctic, as is proved by the character of the fauna in the contemporaneous undisturbed shelly clays of the 100-feet terraces and beaches.

Such, stated as shortly as may be, are the main facts that led me to conclude that our 100-feet beach and the contemporaneous morainic accumulations indicate a distinct stage of the Glacial Period. There was clear proof that a readvance of active glaciers had taken place after the ice-sheet of the upper bowlder clay had vanished from our low grounds, and from the lower reaches at least of our mountain valleys. But, as I remarked in my former communication to this JOURNAL, it was not quite so evident that the readvance in question had been preceded by a definite and prolonged interglacial epoch. The only evidence of preceding relatively genial conditions are the shells which the Loch Lomond glacier took up from the old sea floor and included in its moraines.

It was with these facts and inferences in view that I approached the examination of the Upper Diluvium of North Germany. Perhaps it may be objected that I had no right to expect that the glacial succession in Britain should correspond with that of the Continent, and, if we descend to details of minor importance, that is no doubt true enough. But so far as the chief stages of glacial accumulation are concerned, these must have followed in the same order throughout Europe. I do not suppose, for example, that any geologist will doubt that the epoch of maximum glaciation was one in Britain and the Continent, and the same must be true of other well-marked divisions of the glacial system. I think, therefore, that I was justified in my expectation that the Upper Diluvium of Germany would prove no exception to the rule. If the valley-moraines of the British mountains, which I formerly took to be the degenerate relics of our minor ice-sheet, mark in reality a recrudescence of glacial conditions, it was not improbable that the German Upper Diluvium would have a similar tale to tell.

Now, in the first place, the Upper Diluvium of North Germany closely resembles, in all essential particulars, the British upper bowlder clay with its associated deposits. Along the southern limits reached by the former we encounter banks and undulating hillocks and sheets of gravel and sand, just as is the case with our upper bowlder clay. Like the latter, also, the upper *Geschiebelehm* is often covered with wide stretches of water-worn materials and sprinkled with erratics. So, again, no terminal moraines present themselves as we traverse the country from south to north, until we are suddenly confronted with the great moraines of the Baltic Ridge. Here, then, we cannot but recognize a general resemblance, at least, between the glacial phenomena of Britain and North Germany. In the published works of German geologists I could meet with no evidence to show that the bowlder clay in front of the Baltic Ridge moraines was identical with the bowlder clay behind them. This identity appeared to me to have been taken for granted. At all events, no doubt had been expressed upon the subject, and no attempt made to demonstrate that the two upper bowlder clays are one and the same. Even in the paper to which I am now replying Dr. Keilhack does little more than reiterate his and his colleagues' opinions that the bowlder clays in question are contemporaneous. Apparently he thinks that their interpretation of the evidence ought to be accepted on the ground of their intimate knowledge of the glacial accumulations of their country. I need hardly say that the accuracy of their observations is not called in question. I doubt if their works have, out of Germany, gained the attention of a more admiring student than myself. Their descriptions, wherever I have been able to test them in the field, have proved, as might have been expected, full and exact. It was not without hesitation, therefore, that I found myself unable to accept their explanation of the evidence. I was consoled, however, by the reflection that they themselves are not agreed as to the precise mode of formation of the Baltic Ridge moraines. When geologists, who claim a long acquaintance with the same facts, cannot yet agree amongst themselves as to how those facts are to be interpreted, I may be excused for forming an independent opinion. Having for many years mapped and studied glacial deposits in my own country—and such deposits are much the same in all well-glaciated lands that I have visited—I did not feel incompetent to weigh the evidence and judge for myself as to its meaning.

Dr. Keilhack does not, in my opinion, strengthen his position when he states that in numerous places the ground-moraine in front of the great terminal moraines of the Baltic Ridge passes smoothly under these. If continuous sections showing such connection are in existence, I confess I have never seen or heard of them. Possibly Dr. Keilhack only infers that the bowlder clay which he sees passing under the moraines is the same as that which overspreads the region on the other side. Be that as it may, I have not said and do not maintain that all the bowlder clay lying north of the terminal moraines is younger than the bowlder clay which occurs south of them. I am quite prepared to believe that in many places the terminal moraines have been dumped upon the bowlder clay of the Polandian stage. Further, I do not doubt that the same bowlder clay actually extends over wide areas behind the moraines, but, if such be the case, it must be largely worked up into or concealed underneath the ground-moraines and other accumulations of the great Baltic Glacier.

I now come to Dr. Keilhack's criticism of certain facts which have been adduced by me in support of the conclusion that the terminal moraines of the Baltic Ridge are deposits of a separate and independent glacial epoch.

(1) In Denmark and Schleswig-Holstein two bowlder clays have been for a long time recognized. Both of these occur over the eastern section of that region. To that region the upper bowlder clay is confined, while the latter extends westward to the shores of the North Sea. Both clays are charged with the same assemblage of erratics, the character of which shows that the ice which brought them moved out from the Baltic and traveled in a general westerly direction. In Holland

there is only one bowlder clay—that of the Saxonian stage or epoch of maximum glaciation—and it is crowded with erratics which have come from the north. The lower bowlder clay of Schleswig-Holstein and Denmark cannot, therefore, have been formed at the same time as the Dutch deposit. The latter indicates an ice flow from north to south—the former an ice flow from east to west approximately. The "lower bowlder clay" of the Cimbric peninsula is not the product of the Saxonian ice-sheet, but of its successor, the Polandian. This inference is greatly strengthened by the fact that the so-called "lower bowlder clay" of Schleswig-Holstein is underlaid by well-marked interglacial beds, which in their turn rest upon a yet older bowlder clay—in all probability belonging to the Saxonian stage. Thus we have actually three bowlder clays in the Cimbric peninsula. The uppermost and youngest of the series is confined to the eastern or Baltic side of the peninsula, and is, I believe, the product of the last great Baltic Glacier—the terminal moraines of which appear to form its outer margin. It may be added that freshwater deposits, containing relics of a characteristic interglacial flora (indicative of genial climatic conditions) have quite recently been detected in the neighborhood of Copenhagen, and thus well within the area overflowed by the Baltic Glacier. The deposits referred to are covered by the morainic accumulations of that glacier, and are underlain by diluvial gravels and bowlder clay of an earlier glacial epoch. Dr. Gunnar Andersson remarks of these interglacial beds that they have certainly been accumulated during the time that elapsed between the melting of the great Scandinavian ice-sheet and the invasion of Zealand by the last Baltic Glacier.[1]

Dr. Keilhack's remarks on the evidence cited by me and the inferences I have drawn are somewhat vague, and he ignores the occurrence of the interglacial beds and underlying bowlder-clay, which are proved to occur below the so-called "lower bowlder clay" of Holstein. He states, what is quite true, that no single erratic can be taken as a guide to the direction in which an ice-sheet has flowed. But if by this he means that we cannot decide upon the direction of ice flow from a consideration of the general assemblage or facies of the stones in any given bowlder clay, I cannot possibly agree with him. I am well aware of the fact that every now and again erratics occur in bowlder clay, whose presence would seem to indicate a different direction of ice flow from that suggested by the others in their neighborhood. In regions which have been overflowed by ice at different times and in different directions, such occurrences must be expected. But in the case of the bowlder clays of the Cimbric peninsula it is not merely a few sporadic stones of eastern derivation that we have to deal with. The whole mass of the materials of the two bowlder clays which appear at the surface has traveled from east and northeast, So, again, the bulk of the stones in the Dutch bowlder clay have come from the north.

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[1] Bihang till K. Svenska Vet.-Akad. Handlingar. Bd. 22. Afd. iii. No. 1 1896.

(2) Following De Geer, I maintain that the strong belt of terminal moraines which extends from Hango Head in a northeasterly direction through Finland, are contemporaneous with those of the Baltic Ridge. Referring to the observations of the accomplished geologists of the Geological Commission of Finland, I cite the fact that two distinct systems of glacial striæ are apparent in that country. "The striæ of the one system run in parallel directions, and extend far east and southeast of the terminal moraines. The other and younger system, on the other hand, is bounded by these moraines — the later striæ crossing the older series at various angles. When striæ belonging to both systems appear on one and the same rock-surface, the younger are always the fresher of the two, the older ones being worn and abraded. The latter, according to Rosberg, are the products of a general *mer de glace*, which attained so great a thickness that minor inequalities of the ground had little or no influence in deflecting the ice flow, which extended far beyond the limits of the terminal moraines. The ice, underneath which the younger system of striæ came into existence,

must have been relatively thin, in consequence of which the inequalities of the ground produced endless local divergences from the general direction of ice flow."[1] The small sketch map of the great Baltic Glacier given in my book is largely a reproduction of De Geer's map, published some years ago. According to Dr. Keilhack the line of union drawn from East Prussia to Finland is "purely hypothetical and supported by no observations." Here, however, he is mistaken. Let him consult De Geer's recent work, *Om Skandinaviens geografiska Utveckling efter Istiden,*" and he will find that a great terminal moraine, marking the edge of the Baltic Glacier, traverses the islands of Ösel and Dagö in a north-south direction, and can even be traced for some distance on the bed of the sea. This can hardly be other than a continuation of the terminal moraines (Salpausselkä) at Hango Head.

Dr. Keilhack says he looks "for the easterly continuation of the Baltic terminal moraine much further south, in the interior of Russia." Well, it is never safe to prophesy, but I shall be surprised if his anticipations prove correct. That much gravel and sand and many erratics will be met with in the regions he refers to I can well believe, but all these, I think, will be found to be similar in character and age to the diluvial gravels, etc., which overspread the bowlder clay in the lands to the south of the Baltic Ridge. According to Dr. Vogt, of Christiania, with whom Dr. Keilhack agrees, "the Finnish terminal moraine belongs with that of middle Sweden and Norway." On the other hand, De Geer shows that the terminal moraines which occur in Norway, somewhat south of Lake Mjösen, represent the front of the Baltic Glacier during a stage in its retreat. He traces the position occupied by the ice edge right across Sweden in an easterly and northeasterly direction. The glacier is represented as filling the upper section of the Baltic basin and reaching as far south only as Åland. The great gravel-ridge at Hämeenkanga, in the middle of western Finland, would appear to be its terminal moraine in that country. This moraine occurs about 125 miles north of the older belt that extends from Hango Head to the north of lake Ladoga.

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[1] Great Ice Age, 3d edit., p. 474.

(3) Dr. Keilhack's third criticism has already been met by the remarks I have made on the subject of the upper bowlder clay of Britain. My worthy critic could not have read my work with attention or he would hardly have attributed to me the strange statement that my belief in the confluence of Scandinavian and British ice-sheets, during the formation of our upper bowlder clay, was suggested by and based on the occurrence in that deposit of Scandinavian erratics! He says: "It seems to me unnecessary entirely to repudiate the opinion of the north German geologists in order to explain the occurrence of Scandinavian bowlders in the upper bowlder clay of Britain." I have nowhere said that Scandinavian bowlders occur in our upper bowlder clay. So far as I am aware such erratics are confined to the lower bowlder clay of East Anglia and the midlands of England. Not one has been met with in any bowlder clay of East Britain north of Flamborough Head. The evidence which shows that our upper bowlder clay was formed at a time when "inland ice" filled up the basin of the North Sea, and the Scandinavian and British ice-sheets were confluent, has nothing whatever to do with the occurrence in our country of Scandinavian erratics. The great extension of ice which characterized the formation of our upper bowlder clay is demonstrated, as I have shown above, in quite another way. When Dr. Keilhack has duly weighed our evidence he will no longer consider "whether the connection of the Scandinavian with the Scottish ice in the third glacial period is more than imaginary." The fact of that connection is as well established as one can expect it to be.

(4) Believing as I do that the terminal moraines of the Baltic Ridge are the products of a distinct glacial epoch, I naturally hold that the superficial or youngest morainic accumulations which lie behind those moraines are of later age than the ice-sheet of Polandian times. Thus, I maintain that the upper bowlder clay throughout the region extending from the

Baltic Ridge to the shores of the Baltic Sea, is a younger deposit than the bowlder clay that stretches south from the Baltic Ridge to the valley of the Elbe. Further, I hold that the youngest interglacial beds, which occur between the upper and lower bowlder clays of the Baltic coast lands, are necessarily of later date than the interglacial beds which are met with in the regions lying to the south of the Baltic Ridge. Dr. Keilhack remarks that this is a "false conclusion," by which I suppose he means merely that he does not agree with me. It will be time enough, however, to call my conclusions false when he has succeeded in proving that the upper and lower bowlder clays of the Baltic coast lands are of the same age as the upper and lower bowlder clays of the Elbe valley. At present he merely assumes that they are, and expects me to accept his dictum in lieu of direct evidence or reasonable argument.

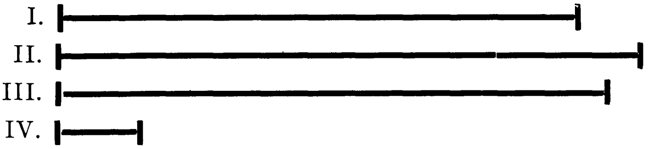
Dr. Keilhack further remarks that if I am right in my view that the terminal moraine of the Baltic Ridge defines the southern limits of a distinct glaciation, he cannot understand why each of the other terminal moraines occurring to the north of it may not also represent the edge of the ice during a distinct glacial epoch. "On this basis," he says, "the so-called 'last glacial epoch' would have to be divided into four if not five epochs, so that even the most fanatical advocate for as many glacial periods as possible would be terrified." I am sorry if Dr. Keilhack cannot distinguish any difference between the position and character of the very pronounced terminal moraine of the Baltic Ridge and the distribution and character of the minor moraines of retreat which lie behind it. For myself I have no more difficulty in distinguishing between the two sets of moraines than I have in the case of the morainic ridges of the inner zone of the Alpine *paysage morainique*. In Britain, just as in the Alpine Vorland and in north Germany, the large moraines of our district- and valley-glaciers are succeeded by numerous smaller moraines of retreat. In North America, also, geologists find no difficulty in differentiating between the first zone of great moraines of the Wisconsin formation, which mark the edge of a separate ice-sheet, and the moraines of retreat that occur behind them.

The southern limits of the Polandian ice-sheet in Britain and Germany alike is bordered by more or less thick banks and sheets of morainic gravels. These are the only terminal moraines connected with the ground-moraine of that ice-sheet. Although the surface of that ground-moraine is often abundantly strewn with fluvio-glacial detritus it shows no lines of terminal moraines comparable to those of the Baltic Ridge in Germany and of the valley-glaciers and local ice-sheets in Britain. The latter bear witness to vigorous glacial action—they have not merely been dumped upon the ground, for the local ice-flow has in many places ploughed into and pushed up preëxisting bowlder clay and ground out hollows in the solid rocks. The terminal moraines of the Baltic Ridge no doubt consist largely of water-worn materials, just as is the case with the moraines of all sheet-like or Piedmont glaciers, and much of the material has been dumped. But they also yield evidence of glacial push, for ground-moraine, confusedly commingled with gravel and sand, not infrequently enters into their composition. The lines of moraines and the irregular mounds, banks, and sheets of water-worn materials which are distributed over the ground between the Baltic Ridge and the shores of the Baltic Sea are simply moraines of retreat and fluvio-glacial deposits, and I hope no "fanatical" glacialist will "terrify" either himself or Dr. Keilhack by suggesting that they indicate "four if not five" separate glacial epochs.

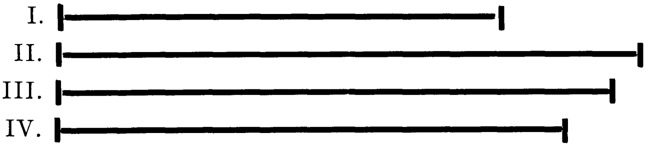
(5) Dr. Keilhack further objects to my conclusion that the terminal moraines of the Baltic Ridge mark the limits of an independent glaciation, because he thinks these moraines cannot be correlated, as I have supposed, with the Alpine valley-moraines belonging to Professor Penck's "first postglacial stage." The Baltic Glacier of my fourth glacial epoch (Mecklenburgian), according to him was of such immense size and so little inferior to the ice-sheets of earlier stages that such correlation as I have attempted is almost impossible. And he gives a graphic repre-

sentation to show the "unnaturalness" of my classification. Such graphic representations, however, unless they are constructed on sound principles, are apt to express rather the views of the draughtsman than the actual facts of nature. Dr. Keilhack's diagrams are, in my opinion, constructed on a wrong principle, and were I to draw similar diagrams they would show a different result. But as my critic would probably be no more satisfied with my graphic representation than I am with his, I prefer to give one constructed a year or two ago by an independent authority—Dr. Du Pasquier, whose recent untimely death every student of glacial geology must deplore. For purposes of comparison Dr. Keilhack's diagrams are also given.

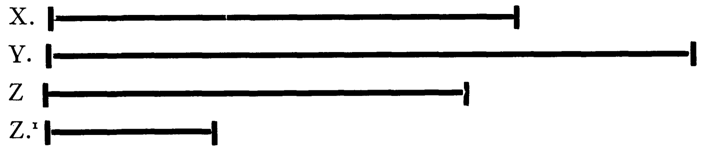
Alps (Keilhack).



North Europe (Keilhack).



Alps (Du Pasquier).



The first thing that strikes one in comparing Dr. Keilhack's representation of the Alpine glacial system with that given by the eminent Swiss geologist is the discrepancy between the lines representing the last three glacial stages (II,III, and IV of Keilhack; Y, Z, Z^1, of Du Pasquier). Dr. Keilhack obtained his lines by simply measuring the length of individual glaciers on the north side of the central Alps, but Du Pasquier has followed a differ-

ent plan. He says: "La longueur des lignes représentant les glaciations successives est proportionelle aux aires glaciées. Le rapport des aires glaciées aux différentes époques X, Y, Z, Z^1, est presque identique dans le Nord de l'Europe et dans les Alpes, et paraît devoir être exprimé par: 0,7 (?) : 1 : 0,66 : 0,27 en moyenne."[1]

If Dr. Keilhack, instead of estimating the extent of the several ice-sheets of northern Europe by drawing lines from the north end of the Gulf of Bothnia into Germany, will contrast the superficial areas of the successive glaciations he will probably come nearer the truth. He will, at all events, ascertain that De Geer's great Baltic Glacier (Mecklenburgian) large though it was, yet covered a much smaller area than that occupied by the preceding Polandian ice-sheet. Nothing could be more absurd than to describe the last great Baltic Glacier as being "little inferior to those of earlier epochs." It was very much inferior, and quite comparable, as Du Pasquier has said, with the Alpine valley-glaciers which are represented in his diagram by the line Z^1.

In correlating the Alpine valley-moraines of Professor Penck's "first postglacial stage" with the terminal moraines of the great Baltic Glacier I was well aware that no interglacial beds had been observed underlying the former. I knew quite well that the valley-moraines in question were generally considered to mark pauses in the retreat of the great glaciers of the inner zone. Latterly, however, Du Pasquier had begun to doubt if such were really the case. Quite recently he had detected evidence to show that the formation of the moraines of the "first postglacial stage" had been preceded by an interglacial interval of fluviatile or lacustrine accumulation. As Du Pasquier's observations are the first of the kind recorded, I shall quote what he says on the subject:

> Au-dessus de l'étage glaciaire Z (see his diagram) encore deux ou trois systèmes de moraines au moins, se terminant vers l'aval en nappes d'alluvions précèdent les moraines actuelles. Ces systèmes, très clairement marqués

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[1] See Bulletin de la Soc. Neuchat. de Geogr., VIII (1894–5).

dans les Alpes, se retrouvent en Ecosse; ils ne paraissant pas avoir encore été suffisamment étudiés ailleurs. Ces moraines terminales, échelonnées le long des vallées, marquent-elles simplement, comme on l'admet d'ordinaire, des moments d'arrêt dans la retraite générale des glaces? Il nous paraît bien douteux qu'il ne s'agisse que de cela. D'abord, comme nous l'avons dit en traitant des glaciers actuels, les moraines terminales ne se produisent guère que pendant l'arrèt qui sépare une phase de crue d'une phase de décrue consécutive. D'autre part, dans notre Jura en particulier, certaines localités nous présentent, entre les moraines Z et d'autres subséquentes soit Z^1, des dépôts fluviaux ou lacustres assez considérables qui font penser que le drainage glaciaire avait fait place à un drainage fluvial. Ces moraines jurassiennes Z^1, nous paraissent être equivalentes à certaines moraines alpines qui forment un ensemble bien caractérisé et qui seraient elles-mêmes équivalentes aux moraines dites baltiques de l'Europe septentrionale. Nous pensons donc plutôt que ces moraines Z^1, marquent une époque glaciaire distincte, sans préjuger en aucune façon de la valeur de l'intervalle interglaciaire qui les sépare de l'époque Z et qui dut, à en juger par l'importance relative des phénomènes d'altération, être bien plus court que les précédents.[1]

I have now I think taken note of all Dr. Keilhack's remarks and criticisms which seem to call for any reply.

JAMES GEIKIE.

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[1] Loc. cit.